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Management in Practice

Long-term management of the invasive *Pacifastacus leniusculus* (Dana, 1852) in a small mountain stream

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Abstract

Pacifastacus leniusculus (an invasive species in European water bodies) was detected for the first time in the Andalusia Region (S. Spain) in the year 2000. Since 2005, a continuous control management programme has been carried out by the Environmental Regional Government. Management efforts aimed to reduce the population size, to contain the dispersal and reduce the probability of deliberate translocation into other rivers caused by illegal captures. A combination of techniques was used, including crayfish traps, manual removal from artificial refuges and electrofishing. In the 2005-2009 period, 31 374 specimens were captured. The mean catch rate per worker and day declined from 30.4 ± 3.2 specimens in the first year to 9.8 ± 1.7 in the fourth year, therefore suggesting a sharp decrease in population size. Summer was the period of mating and maximum yields, whereas minimum yields were obtained in Winter, coinciding with egg incubation in burrows. The results obtained and the experience gained will provide essential baseline information for the future management of non-native crayfish in the region.

Key words: non-native, introduction, signal crayfish, invasion, containment, Spain

Introduction

Pacifastacus leniusculus (Dana, 1852) (Crustacea: Astacidae) is an invasive North American crayfish species that has become widely introduced and successfully established throughout Europe in numerous rivers and streams since the 1960s (Gherardi and Holdich 1999; Holdich 2002; Souty-Grosset et al. 2006) for fishing. However, the introduction of this species has posed different environmental problems such as decimating invertebrates and aquatic plants through predation and destabilising river banks by burrowing (Nyström et al. 1996; Stebbing et al. 2004; Rosenthal et al. 2006). This species has also been partially responsible for the decline of several indigenous European crayfish species through competition and transmission of aphanomycosis (crayfish plague) (Westman et al. 2002; Souty-Grosset et al. 2006).

The first and until now, only population of *P. leniusculus* known in Southern Spain was detected in 2000 in the Riofrío River (Loja, Granada) as a well-established population located close to a fish-hatchery. The upper part of the river harboured an important population of *Austropotamobious pallipes* (Lereboullet, 1858), an endangered species according to regional, national and European laws. This species has been traditionally fished by local people until the 1990s but nowadays, only isolated individuals can be occasionally observed. Besides this, the risks of downstream dispersal, illegal fishing of *P. leniusculus* by citizens (as a substitute for the native species as in the case of the red swamp crayfish, *Procambarus clarkii* (Girard, 1852)) was considered as an additional risk that could lead to repeated translocation and introduction into neighbouring aquatic habitats and streams. As a consequence, in 2005, the Regional Environmental Council (Consejería de Medio

Ambiente) of Andalucia (a territory of 87 268 km^2), considered the incipient invasion of *P. leniusculus* as an urgent problem that need to be managed. The short-term goals were to: 1) maintain a physical presence of the Public institution through field staff that could help to diminish illegal fishing, 2) reduce the population size of the invasive species and subsequently, a) increase the effort needed for local fishermen to obtain their captures, b) decrease the risk of downstream dispersal, and c) to gather practical experience on the management on the species, which could be used to deal with invasions in similar scenarios. However, no previous published reports on successful control measures and techniques were found (see Holdich et al. 1999; Stebbing et al. 2004). No time was available for previous analysis of population features and ecological processes involved. Therefore, an adaptive management approach was adopted (Meffe et al. 2006; Williams et al. 2007) in order to improve management efficiency and to correct the suboptimal solutions chosen at initial stages.

The aim of this paper is to report the results of the long-term management of the invasive *Pacifastacus leniusculus* obtained in the period from August 2005 – August 2009, and to show how some management limitations at initial stages can be overcome with an adaptive management approach.

Materials and methods

Area of study and fishing techniques

Control measures for *Pacifastacus leniusculus* were conducted in the Riofrío River (37º09´6.7´´N; 4º12´20.5´´W), a small mountain stream (11 km length; 700-800 m altitude) with a Mediterranean climate. The river bed consists of patches of mud (2%), sand (33%) and gravel (65%) with abundant plant roots on the banks. The riparian vegetation is dominated by *Ficus carica*, *Salix* sp., *Rubus ulmifolius*, *Fraxinus angustifolia, Populus alba* and *Ulmus minor*. For the first year (August 2005), crayfish traps were set along the river (every 50 m) to analyse the species distribution and to establish the upper and lower boundaries of the population. Sampling was repeated annually. Preliminary work was undertaken to remove rubbish and closed riparian vegetation to increase the river accessibility for workers. Intense fishing was then carried out using a combination of three techniques: (1) Baited crayfish traps (similar to minnow traps) (Figure 1) were set in areas with difficult access for workers (depths > 1 m). Traps were 0.5 m long and 0.3 m in diameter, with rings of 0.65 m diameter, and 5 mm square mesh. Nets were left in the river and emptied every 24 h. Trout and herring were used as bait (1/4 fish per trap) and were set hanging inside the trap using safety pins (Figure 1) to avoid their consumption by crayfish arriving from outside the trap. (2) Artificial refuges had an area of 1 m^2 (n = 25), 4 m^2 (n = 34) and 6 m^2 (n = 31) and were built with stones (10-50 cm length) from the bed of the river mixed with a number of bricks. Artificial refuges were located on shallow (< 0.5 m) banks of the river and were manually emptied every 24 h. Previous experiences showed that artificial shelters attracted crayfish that were more accessible to workers. (3) Electrofishing was selected as a complementary technique from the year 2009, once catches became established and no significant changes were observed. The crayfish were captured with Hans Grassl GmbH ELT 6011 GI Honda GXV50 electrofishing gear, using 25-50 Hz current with a voltage of 200–400 V.

Efforts were subjectively adapted to staff availability (8 to 80 work days per month, mean 40 ± 18). Under these management conditions, the main problems encountered were due to: (i) variability of fishing efforts due to marked seasonal variability in species activity (e.g. lower yields in winter due to hatching inside burrows); (ii) heterogeneous accessibility to riverbank refuges, which could lead to lower yields in some stretches and a subsequent increase in recruitment; (iii) uncontrolled visits by local people with occasional vandalism (e.g., trap robbery); (iv) scarce biological and ecological information for the area invaded (e.g. repeated census, recruitment rates, microhabitat distribution of age classes) either previous or simultaneous to population reduction.

Data collection

Each specimen collected was sexed and measured (carapace length, CL, to the nearest 0.1 mm). The observed size ranges of mature females showing any of the different reproductive stages (maculation during mating, egg or fry carrying) was used to classify *P. leniusculus* specimens into two groups: juveniles and sub-adults (CL<20 mm) and adults.

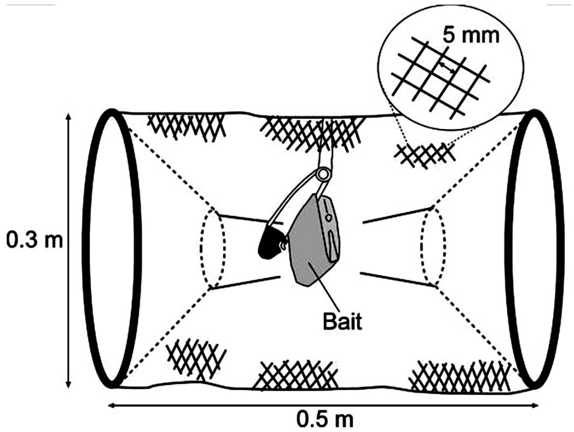

Figure 1. Detail of the crayfish trap used, showing the layout of the bait inside.

This gave information on the present age-classes, cohorts and changes in population structure during management efforts.

Relative abundance of the population was expressed as catch-per-unit-effort (CPUE = number of individuals fished per total work days (considering a combination of hand collection in artificial refuges and trapping). This parameter has been confirmed to be a good indicator of the relative abundance of crayfish (Shimizu and Goldman 1983; Skurdal et al. 1995).

Estimation of population size

In Summer 2009, the size of the signal crayfish population (highest population activity and catchability of juveniles), was estimated by a modification of the capture-mark-recapture method (Ricker 1975). This 2009 estimate of the overall population seemed to have reduced from previous years, and more precise information became necessary for evaluation of capture efficiency. This population size estimate served as a reference level to be compared with captures and thus obtain an annual indicator of capture efficiency and the crayfish number that remained to be captured. Mean estimated longevity of *Pacifastacus leniusculus* is between 6 to 16 years, the amplitude of the range varying with site conditions and techniques employed for age-estimate (e.g. Mason 1963; Belchier et al. 1998). Population estimates are also key to assessing population trends and future eradication feasibility.

Statistical analysis

Yearly CPUE (August 2005-August 2009) data were tested for normal distribution by a Kolmogorov–Smirnov test. Barlett's and Levene's tests of equality of variances were also performed. Differences among yearly CPUE were subsequentally tested by non-parametric estimators (Kruskal-Wallis and Mann Whitney tests). Differences were considered significant when $p < 0.05$.

Results and discussion

P. leniusculus is distributed along a stretch of 850 m with a mean depth of 0.2 m (0.0-0.9 m) and a mean width of 4 m (1.6-14.4 m). The upstream and downstream geographical boundaries of the population remained constant during the study. Overall CPUE showed a significant decrease between years (Kruskal-Wallis; $\chi^2 = 24.82$; $p < 0.001$) (Figures 2 and 3) with a total of 31 374 individuals removed from the Riofrío River between August 2005 - August 2009. Paired comparisons between years showed a significant reduction of total CPUE during the initial stage of measures (Table 1). This was probably due to the high population density and the greater abundance of large adult individuals at the initial stage of field work (Figure 2). Adult specimens are more easily observed by field workers either in artificial refuges or when electrofishing. During the last three years, CPUEs showed significantly lower values than in the first year, however, a significant decline was not detected between years in the 2006-2009 period. A similar pattern has been found in other long-term management studies reported for controlling invasive crayfish (e.g. Hein et al. 2007). Considering the different age-classes, CPUE of adults showed no significant reduction since 2006 (Table 1, Figure 3). Juveniles and sub-adults also showed a progressive reduction of CPUE which was significant in 2009 with respect to previous years. It must be taken into account that detection and catchability decrease as a consequence of a density reduction. These results suggest that the invasive population has remained rather constant in size, and therefore, current catching efforts appear to have been paired with natural recruitment. Therefore, catching efforts by artificial refuges and baited traps in 2006-2008 appear to have been useful to control natural recruitment of the invasive population.

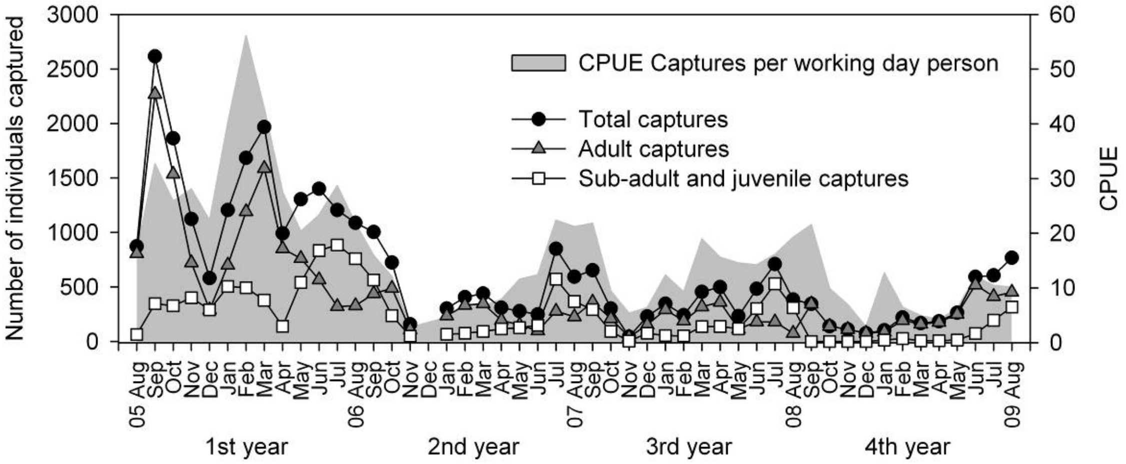

Figure 2. Evolution of the number of individuals captured (total, adults, sub-adults and juveniles) and CPUE during the study period.

Table 1. Results of U Mann-Whitney test of differences in CPUE between paired years.

Years (paired comparison)		Total		Adults (>20mm CL)		Juveniles and sub-adults (< 20 mm CL)	
		U	p-value	U	p-value	U	p-value
1	2	5.0	<0.001	1.0	<0.001	37.0	0.079
1	3	5.0	<0.001	14.0	<0.001	42.0	0.088
1	4	3.0	<0.001	13.0	<0.001	12.0	<0.001
2	3	82.0	0.340	92.0	0.116	71.0	0.781
2	4	54.0	0.479	79.0	0.441	24.0	0.010
3	4	43.0	0.099	58.0	0.435	20.0	0.002

The adult population estimated in 2009 (late summer) was 2086 ± 500 individuals, while the overall captures in 2005 was clearly greater (Figure 2).

The intense removal of large size classes, especially during the first year (Figure 5), could have reduced the species recruitment, since the female's fecundity is related directly to body size (Mason 1975; Soderback 1995). Significant reduction of the abundance of adults and the subsequent dominance in population of age groups with lower fecundity may be facilitating this process. It also should be considered that a reduction of the large specimens could decrease the intraspecific competition for shelter and food, thus enhancing the growth rate and recruitment success (Sibley and Nöel 2002).

CPUE showed a clear seasonal variation (Figure 4) with significant differences between months (Kruskal Wallis; $X^2 = 21.10$; $p < 0.05$) showing maximum yields in summer and minimum captures from early Winter to early Spring. This is due to the reproductive cycle and behaviour of this species (mating encounters, females sheltering in Winter, etc.) and its thermo- photoperiodic response (Abrahamsson 1981; Shimizu and Goldman 1983; Lowery and Holdich 1988; Kirjavainen and Westman 1999; Ribbens and Graham 2004; Capurro et al. 2007) which lead to the yield patterns shown in Figure 4. In agreement with Ribbens and Graham (2004), an increase of the catch effort during the Summer increases the total captures.

The results of the management carried out in 2005-2009 to control the invasive *P. leniusculus* suggest that it is feasible to obtain a certain success in control strategies of an isolated population of *P. leniusculus* within the first 12 months of work by using a combination of fishing techniques (trapping and artificial

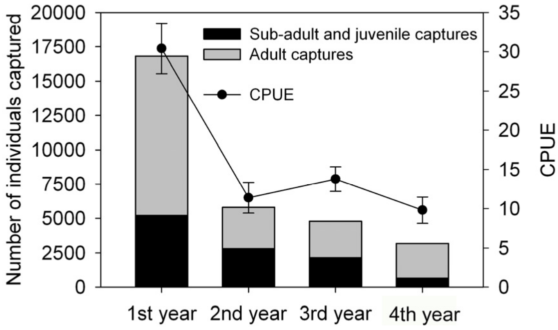

Figure 3. Total number of individuals captured over four years per size class and temporal evolution of CPUE. Each bar represent the mean ± the standard error of n = 4 years.

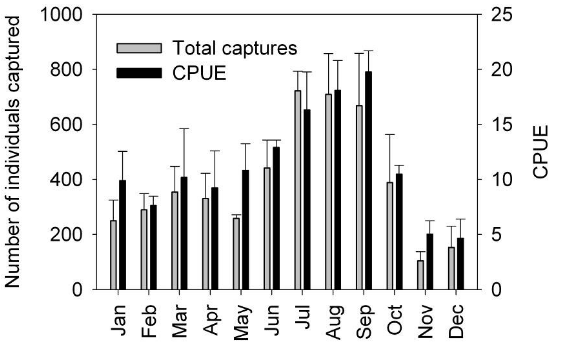

Figure 4. Number of individuals captured per month and CPUE during the last three years. Each bar represent the mean ± the standard error of n = 3 years.

refuges). These techniques may also serve to remove an important fraction of large and mature individuals, causing a significant reduction of population size and recruitment, specially affecting reproductive individuals. However, even when the population has been strongly reduced, the methods used and the continued presence of staff are also useful to contain population and dispersal by discouraging illegal fishing.

Conclusions

Long-term management programmes are necessary to control signal crayfish invasions in aquatic environments. Such programmes require high capture efforts and the use of a combination of methods to capture all size classes in the different micro-environments. However, once

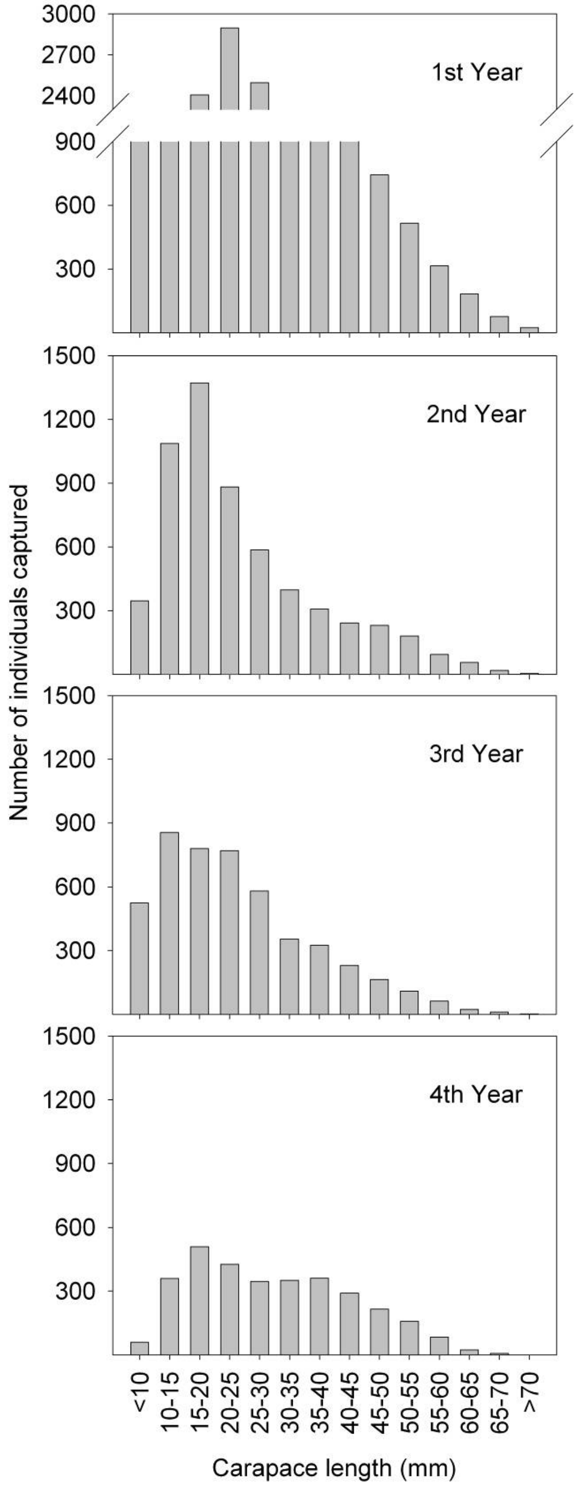

Figure 5. Size-frequency distributions of the individuals collected over four years.

sufficient resources were provided, continued and intensive removal of *P. leniusculus* for four years has reduced the population size and consequently, the risk of natural dispersal or deliberate translocation by local fishermen.

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